307-333, 2007. Examples of laser diode structures are described in U.S. Patent Application Ser. No. 61/181,608.

After growth, the $Al_xIn_yGa_{(1-x-y)}N$ epitaxial layer may be removed from the substrate by methods that are known in the art to form a free-standing $Al_xIn_yGa_{(1-x-y)}N$ layer, crystal, wafer, or boule. At least one surface may be lapped, polished, and/or chemical-mechanically polished. The free-standing $Al_xIn_yGa_{(1-x-y)}N$ layer, crystal, wafer, or boule may have a semipolar orientation; a thickness of at least 100 nanometers, a threading dislocation density below about 10^9 cm^{-2}, a stacking fault density less than about 10^3 cm^{-1}, and a strain less than about 0.1%. The thickness may be at least 1 micron, at least 10 microns, at least 100 microns, or at least 1 millimeter. The dislocation density may be less than 10^8 cm^{-2}, less than 10^7 cm^{-2}, or less than 10^6 cm^{-2}. The stacking fault density may be less than about 10^2 cm^{-1}, less than about 10 cm^{-1}, or less than about 1 cm^{-1}. The strain may be less than about 0.01%, less than about 10^{-5}, or less than about 10^{-6}.

Active layer(s) may be deposited on the $Al_xIn_yGa_{(1-x-y)}N$ epitaxial layer or on the free-standing $Al_xIn_yGa_{(1-x-y)}N$ layer, crystal, wafer, or boule. The active layer may be incorporated into an optoelectronic or electronic devices such as at least one of a light emitting diode, a laser diode, a photodetector, an avalanche photodiode, a transistor, a rectifier, and a thyristor; one of a transistor, a rectifier, a Schottky rectifier, a thyristor, a p-i-n diode, a metal-semiconductor-metal diode, high-electron mobility transistor, a metal semiconductor field effect transistor, a metal oxide field effect transistor, a power metal oxide semiconductor field effect transistor, a power metal insulator semiconductor field effect transistor, a bipolar junction transistor, a metal insulator field effect transistor, a heterojunction bipolar transistor, a power insulated gate bipolar transistor, a power vertical junction field effect transistor, a cascode switch, an inner sub-band emitter, a quantum well infrared photodetector, a quantum dot infrared photodetector, a solar cell, and a diode for photoelectrochemical water splitting and hydrogen generation.

The InGaN substrates described herein allows the development of a new class of III-nitride visible-spectrum devices that will have superior performance throughout the visible spectrum and allows the realization of maximum efficiencies for systems employing these in applications, such as illumination and displays.

The embodiments described herein are examples of compositions, structures, systems and methods having elements corresponding to the elements of the invention recited in the claims. This written description enables one of ordinary skill in the art to make and use embodiments having alternative elements that likewise correspond to the elements of the invention recited in the claims. The scope thus includes compositions, structures, systems and methods that do not differ from the literal language of the claims, and further includes other compositions, structures, systems and methods with insubstantial differences from the literal language of the claims. While only certain features and embodiments have been illustrated and described herein, many modifications and changes may occur to one of ordinary skill in the relevant art. The appended claims are intended to cover all such modifications and changes.

What is claimed is:

1. A method for forming a biaxially relaxed c-plane epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer comprising:

providing a substrate having a surface characterized by an orientation within 5 degrees of a c-plane;

forming a pattern of channels in the substrate and isolated regions of the substrate defined by the channels, wherein the channels are characterized by a sidewall angle with respect to the surface of the isolated regions between 60 degrees and 90 degrees and a pitch ranging from between 10 nm and 1000 nm; and

a surface of the isolated regions is characterized by an orientation within 5 degrees of a c-plane;

growing at least one $Al_xIn_yGa_{(1-x-y)}N$ epitaxial layer on the isolated regions, comprising:

growing a strained epitaxial $Al_xIn_yGa_{(1-x-y)}N$ region on the isolated regions, wherein at least during initial stages of growth the strained epitaxial $Al_xIn_yGa_{(1-x-y)}N$ region comprises a plurality of misfit dislocations; and

increasing a thickness of the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer to cause the isolated regions to close off by lateral growth and to form a coalesced epitaxial $Al_xIn_yGa_{(1-x-y)}N$ region, wherein the coalesced epitaxial $Al_xIn_yGa_{(1-x-y)}N$ region is substantially free of misfit dislocations; and

forming at least one biaxially relaxed c-plane epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer overlying the coalesced epitaxial $Al_xIn_yGa_{(1-x-y)}N$ region, wherein

a total thickness of the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer is at least 100 nm; and

the biaxially relaxed c-plane epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer is characterized by a biaxial strain less than 0.1% and a total threading dislocation density less than 10^8 cm^{-2}.

2. The method of claim 1 wherein at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer comprises at least two epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layers wherein at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer has a graded composition.

3. The method of claim 1 further comprising subjecting the substrate to a roughening process before formation of the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ epitaxial layer.

4. The method of claim 1 further comprising forming a second epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer on a back side of the substrate.

5. The method of claim 1 wherein the total thickness of the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer is greater than 1 micron.

6. The method of claim 1 wherein the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer comprises at least two epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layers characterized by a graded composition.

7. The method of claim 1 wherein increasing the thickness of the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer comprises:

depositing $Al_xGa_{(1-x)}N$ material at a first thickness of less than 100 nanometers;

annealing the $Al_xGa_{(1-x)}N$ material at a temperature ranging from between about 1000 degrees and 1400 degrees Celsius; and

depositing $Al_xGa_{(1-x)}N$ material at a second thickness, wherein the a total thickness of the first thickness and the second thickness is greater than 100 nanometers.

8. The method of claim 1 further comprising removing the substrate and the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer to form a free-standing biaxially relaxed c-plane epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer, crystal, wafer, or boule.

9. The method of claim 1 further comprising fabricating a light emitting diode or a laser diode on at least a portion of the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer.

10. The method of claim 1, wherein the thickness of the at least one epitaxial $Al_xIn_yGa_{(1-x-y)}N$ layer is greater than 10 microns.

11. The method of claim 1, wherein the substrate comprises bulk gallium nitride.

12. The method of claim 1, wherein the substrate comprises sapphire.

13. The method of claim 1, further comprising depositing an additional epitaxial layer by hydride vapor phase epitaxy overlying the at least one $Al_xIn_yGa_{(1-x-y)}N$ layer.